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The influence of coatings on the environmental hygric inertia of plastered rooms / Ronzino, Amos; Corrado, Vincenzo. - In: ENERGY PROCEDIA. - ISSN 1876-6102. - ELETTRONICO. - 78:6th International Building Physics Conference, IBPC 2015(2015), pp. 1507-1512. [10.1016/j.egypro.2015.11.178]

*Availability:*

This version is available at: 11583/2638053 since: 2016-03-22T09:12:48Z

*Publisher:*

Elsevier

*Published*

DOI:10.1016/j.egypro.2015.11.178

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6th International Building Physics Conference, IBPC 2015

## The influence of coatings on the environmental hygric inertia of plastered rooms.

Amos Ronzino<sup>a\*</sup>, Vincenzo Corrado<sup>a</sup><sup>a</sup>*Politecnico di Torino, corso Duca degli Abruzzi 24, Torino 10129, Italy*

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### Abstract

In Italian buildings, especially dwellings, walls are very often plastered with gypsum plaster for levelling purposes. The gypsum plaster is generally covered with waterborne wall paint for decoration which represents a barrier for the water absorption or desorption. To know the hygric performance of a room in such real conditions, the water transfer properties of the painted gypsum must be known. Wall paints can be roughly divided into waterborne and solvent borne paints. Waterborne wall paints are increasingly being used for their low odour and fast environmental friendly drying. The newer waterborne paints are based on aqueous dispersions of synthetic vinyl-type binders, such as polyvinylacetate or polyvinylpropionate (co-)polymers, and acrylic polymers. Moreover, paints containing volatile organic components have recently been prohibited by the European Commission for professional indoor use. The pressure to reduce volatile organic components and the industrial trend towards friendlier products with low toxicity of the product formulation led to the current expansion of waterborne types of coating. In building physics literature, knowledge is lacking about the moisture transfer properties of waterborne wall paints. Also the behavior of painted substrates has not been examined sufficiently. The role of the paint constituents in the moisture transfer properties is unclear. This lack of knowledge is partly caused by the lack of simple measuring techniques. Also the moisture behavior of the gypsum plays an important role in controlling the relative humidity, as the experimental activity in the paper for measuring its hygroscopic properties (Moisture Buffer Value) highlights. Painting gypsum is not done to prevent deterioration of the substrate as usually done for wood; gypsum is mainly painted for decorative reasons: this can also be a means to control the moisture transfer properties of the gypsum. Anyway, aim of the present study is not the numerical modelling or measuring of waterborne paints, but their influence once applied to the gypsum substrate, of which the hygroscopic properties were calculated when coated and uncoated. The numerical simulation using an whole building HAM-transfer model is then used to simulate the hygroscopic performance of a room in different conditions.

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

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\* Corresponding author. Tel.: +39-0110905335.

E-mail address: [amos.ronzino@polito.it](mailto:amos.ronzino@polito.it)

*Keywords:* gypsum plaster, moisture buffering; hygroscopic properties; paint.

## 1. Introduction

In Mediterranean dwellings, as those in Italy, walls are very often plastered with gypsum plaster for levelling purposes and generally covered with waterborne wall paint for decoration, which represents a barrier for the water absorption or desorption. Since the moisture behaviour of gypsum plays an important role in controlling the relative humidity [1], this widespread practice within the building construction affects the hygric performance of the room. As the measurement of the material hygroscopic properties is usually carried out with naked specimens, the water transfer properties of the painted gypsum must be known to evaluate the hygric performance of a coated room by means of numerical simulation.

Wall paints can be roughly divided into waterborne and solvent borne paints. Waterborne wall paints are increasingly being used for their low odour and fast environmental friendly drying [2]. Moreover, paints containing volatile organic components have been prohibited by the European Commission for professional indoor use. In building science, knowledge is lacking about the moisture transfer properties of painted substrates, and therefore the role of the paint constituents in the moisture transfer properties needs to be deepened. This lack of knowledge is partly caused by the lack of reliable and fast measuring techniques [3,4,5,6,7], for fitting numerical and experimental data [8,9]. Painting gypsum is not done to prevent the material deterioration but mainly for decorative reasons.

Aim of the present study is: a) measuring the hygroscopic properties of gypsum with a reliable and fast experimental process; b) evaluating the influence of waterborne paints on the moisture transfer properties of gypsum; c) assess the impact of the application of coatings on the hygroscopic performance of a room, also considering the effect of different ventilation rates.

### Nomenclature

A	area [ $\text{m}^2$ ]
M	water vapor permeance [ $\text{kg}/(\text{Pa m}^2 \text{s})$ ]
$p_v$	water vapor pressure [Pa]
RH	relative humidity [-]
t	time [s]
V	volume [ $\text{m}^3$ ]
w	water content [ $\text{kg}/\text{m}^3$ ]
x	spatial coordinate [m]
$\beta$	moisture surface transfer coefficient [ $\text{kg}/(\text{Pa m}^2 \text{s})$ ]
$\delta$	water vapor permeability [ $\text{kg}/(\text{Pa m s})$ ]
$\varphi$	relative humidity [%]
$\sigma$	standard deviation

## 2. Material and methods

### 2.1. Measuring system

In this research, a commercially available product has been used, composed by premixed gypsum plaster, anidrene, vermiculite, perlite, and specific additives. In this phase two specimens of the same product were prepared to be tested, according to the same gypsum/water ratio and drying time environmental conditions, in order to achieve the same physical and chemical behavior during the following tests. A twin climate chamber device especially designed for this purpose [10] was set up to measure their hygroscopic properties simultaneously by

means of some sorption/desorption step cycles. In the plexiglass measuring device the conditioned air is supplied through a pre and return hose deriving from a mixing box. Moist air is set at specified levels of temperature and relative humidity through a remote control system. The specimen inside the climate chamber is sealed in a XPS box, where only the front surface is subjected to the conditioned air and weighed every 60 seconds for 24 days. Temperature (constant at 23°C) and relative humidity were continuously monitored through sensors positioned on both sides of the specimen, while change in mass due to the moisture content variation was measured for 3 main different RH cycle step changes: 30-50%, 50-70%, 70-90% (Figure 1). The covered range of relative humidity allows the evaluation of the material behavior in the hygroscopic region, excluding liquid transport ( $\phi > 98\%$ ). To minimize the external influences the measuring system has been built in a controlled climate room with constant temperature (22°C) and a relative humidity (50%).

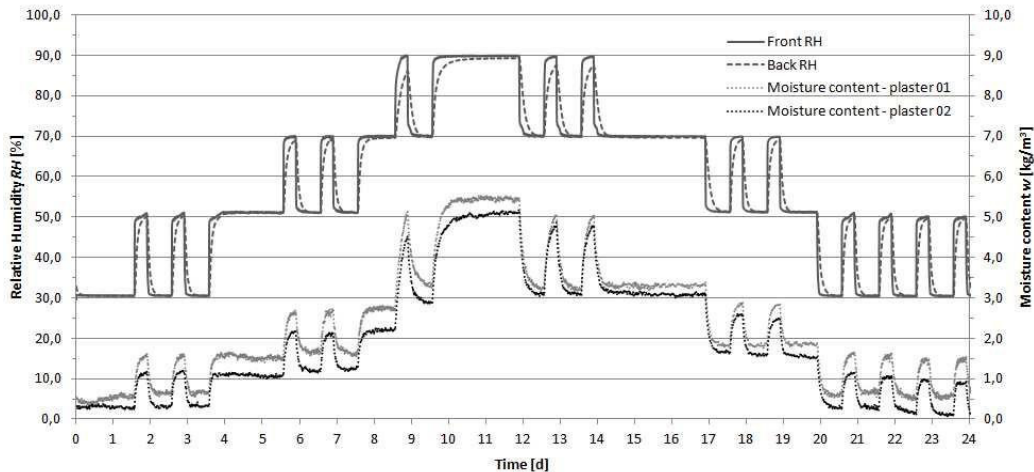


Fig. 1. The measured RH step changes for gypsum plaster. The relative humidity on both sides of the specimen and its moisture content are shown.

## 2.2. Numerical fitting of experimental data

The adopted methodology for the calculation of the vapour permeability and of the equilibrium moisture content at the different relative humidity steps is based on the control volumes method. The 10 mm thick specimen was discretized in 5 internal nodes (cells) and 2 surface nodes (Figure 2). According to recent results from literature [7,10] the vapour permeability and the equilibrium moisture content were calculated starting from Fick's first law equation by means of a numerical simplified method, according to the measured vapour pressures and change in mass due to the humidity variations. The water vapour permeance  $M$  [ $\text{kg}/(\text{Pa m}^2 \text{s})$ ] is calculated for each node at the center of the cells, where  $\Delta x = 2$  mm, and  $\beta_e = \beta_i = 2 \cdot 10^{-8} \text{ kg}/(\text{m} \cdot \text{s} \cdot \text{Pa})$ .

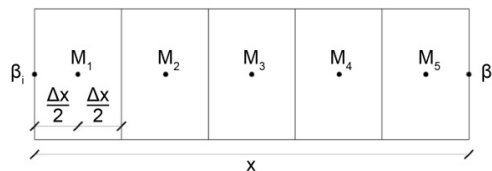


Fig. 2. Discretization of the gypsum plaster specimen according to the control volumes method.

### 3. Results

#### 3.1. Sorption/desorption simulation

The adopted numerical model was then validated by comparing the simulation results to those obtained from MBVsim, a specific arrangement of HAM-Tools modules [10], for each RH cycle step. The results showed that the numerical solutions of both simplified models fit the real behaviour of the tested specimens with very good agreement (Figure 3). The change in mass  $\Delta w$  [g/(m<sup>2</sup>·%RH)] is normalized on the surface area of the specimen and on the applied RH step.

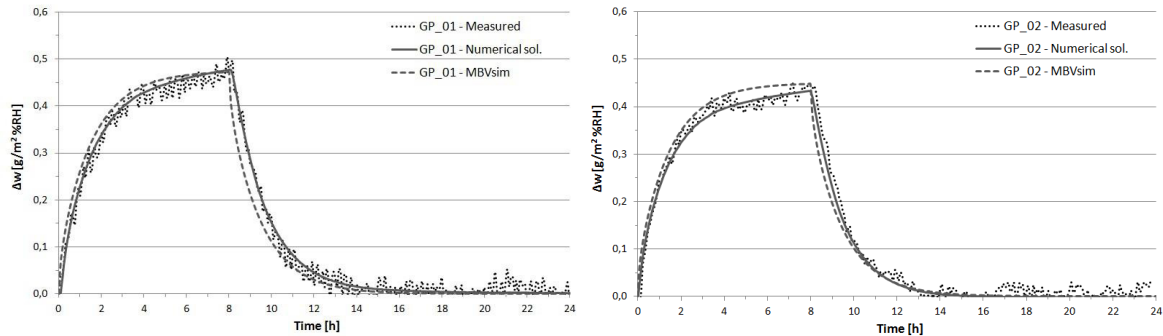


Fig. 3. Fitting curves of the sorption/desorption cycle for 30-50% RH step change. a) specimen n.1; b) specimen n.2.

Probably due to the uncertainty of the measurement instruments and to manual preparation of the specimens, the results show some deviation especially with regard to the sorption isotherms, which are shown in Figure 4.

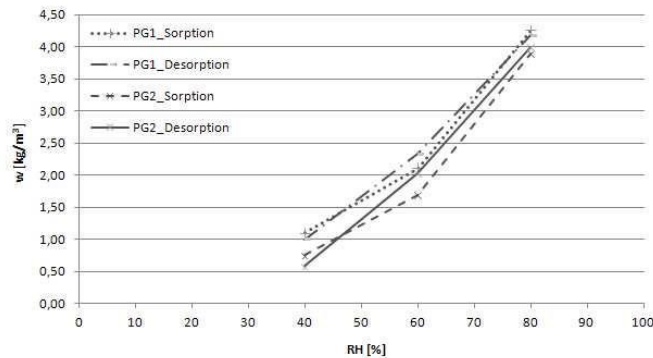


Fig. 4. Sorption isotherms for the two gypsum plaster specimens (PG1 and PG2).

#### 3.2. MBV test simulation for the coated specimens

In order to test the influence of two different commercially available waterborne paints, with two different  $\mu$ -values, the tested specimens were coated. Once the MBVsim model has been validated for the 30-50% RH step, it was possible to reproduce the Moisture Buffer Value (MBV) test in the climate chamber according to the NORDTEST Protocol scheme [11]. In this way the missing data can be simulated with a very good approximation, avoiding time-consuming experiments for additional measurement cycles. In Figures 5 the fitting of the coated specimens are shown and compared to the hygroscopic performance of the naked gypsum plaster simulated with MBVsim. With respect to the previous matching, two aspects differ during the fitting process:

- a minor spread on the measured data can be noticed for the coated specimens with respect to the uncoated ones, probably due to the paint contribution to uniform the material surface;
- a higher deviation is visible during the desorption phase for the data simulated with MBVsim.

In our case, the input data for the material properties in MBVsim -  $\delta(w)$  and  $w(\varphi)$  - are those fitted through the numerical solution. The deviation between the two models leads to the generation of a curve with an increased slope during the desorption process, which turns out to be faster when using HAM-Tools.

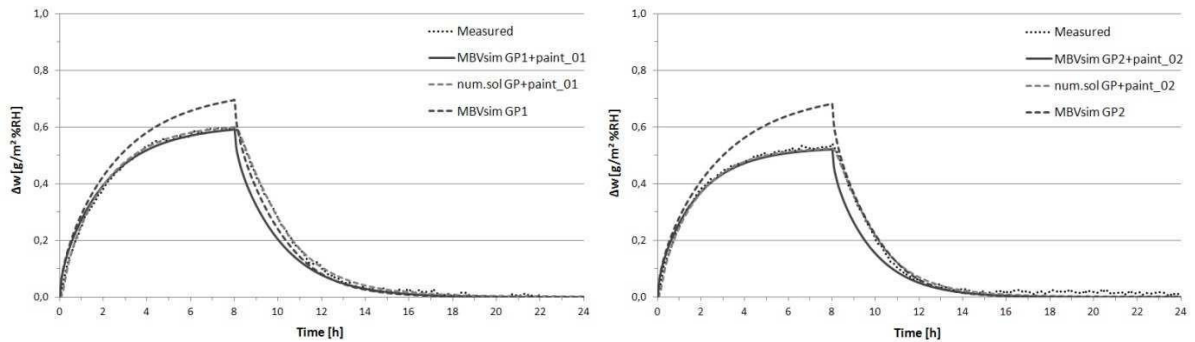


Fig. 5. Fitting curves of MBV test (33-75% RH step change) for the coated and uncoated plasters. a) specimen n.1; b) specimen n.2.

Comparing the measurements for the uncoated and the coated specimens, the results show a decrease in the buffer potential equal to 15 % for the specimen coated with the first paint, while the second paint – which was characterized by an higher  $\mu$ -value – caused a decrease of the MBV equal to 23 %.

### 3.3. Whole room simulation

After the evaluation of the hygroscopic performance at material level for both coated and uncoated gypsum plasters, the room level was investigated. Since the measurements within the climate chamber do not take into account some environmental factors such as the ventilation rate and the influence of the thermal flux on the moisture content of the building envelope, the whole room simulation was performed by using HAM-Tools. In this phase the effect of the moisture buffer capacity for the different coated and uncoated finishing on the environment was studied by monitoring the indoor RH variation at different ventilation rates.

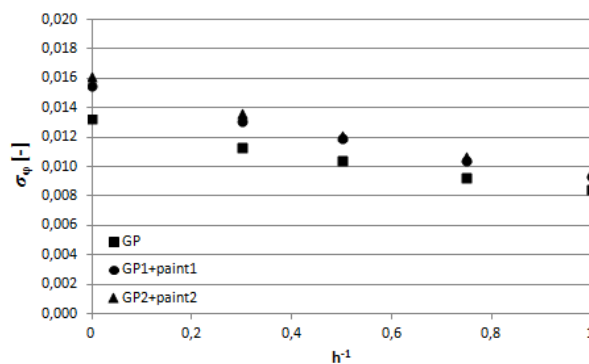


Fig. 6. Standard deviation of relative humidity for the whole week simulation. Results for 0-0,3-0,5-0,75-1 h<sup>-1</sup> ventilation rate for the two coated and the uncoated gypsum plaster finishing.

The simulation has been carried out for the first week of January with Turin weather data (EnergyPlus database) considering a 55 m<sup>3</sup> volume simple room [1]. The air temperature was maintained constant (20°C) and a moisture gain of 40 g/h per person was set for 10 people from 9 to 17 h. The outdoor and indoor moisture transfer coefficients are  $\beta_e = 2 \cdot 10^{-7}$  and  $\beta_i = 2 \cdot 10^{-8}$  kg/(m·s·Pa) respectively; an air change rate of 0.0,3-0.5-0.75-1 h<sup>-1</sup> through a mechanical ventilation system with outdoor relative humidity is simulated. In Figure 6 the standard deviation of calculated relative humidity  $\sigma_\phi$  for all the scenarios considering. The dampening effect of gypsum plaster has a visible impact on the indoor RH cyclic oscillation for the unpainted case, while the dynamic response of the interior components concerning the moisture buffering decreases when the two paints are applied on the gypsum substrate. The increase of the air flow rate leads to decreases the influence of the material properties as well as the moisture gain impact on the oscillation amplitude of indoor RH, since the outdoor air humidity becomes the dominant factor.

#### 4. Conclusions

In this study a methodology to assess the impact of the application of coatings on the hygroscopic performance of a room is applied, considering the effect of ventilation in realistic conditions. The process is carried out by measuring the hygroscopic properties – vapour permeability and the sorption isotherm – of both coated and uncoated gypsum plaster in transient conditions, avoiding time-consuming experiments, and matching simulated and measured data by using a simplified numerical method. Through the HAM modelling it was demonstrated how common and widespread habits as that of painting the interior of residential environments may affect the indoor hygrothermal comfort, i.e. the increase of the relative humidity level. The application of waterborne paints may decrease the MBV of gypsum plaster up to 23% and increase the indoor RH peaks of 2% for the used products and the presented scenarios. In the study the influence of the ventilation on the indoor RH trend was also evaluated with respect to the application of paints, highlighting the decrease of the material contribution on the moisture buffer when the air flow rate is increased up to 1 h<sup>-1</sup>.

#### Acknowledgements

This work was carried out within a research activity supported by Saint-Gobain PPC Italia S.p.A. about the *Influence of hygroscopic interior finishing on indoor comfort conditions*.

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